TITLE OF THE INVENTION

IMAGE PROCESSING APPARATUS AND METHOD

5 ## FIELD OF THE INVENTION

This invention relates to an image processing apparatus and method. More particularly, the invention relates to an image processing apparatus and

10 method for improving the contrast of an image of interest.

BACKGROUND OF THE INVENTION

15 Owing to recent advances in digital technology, it is now possible to convert a radiation image or the like to a digital image signal and subject the digital image signal to image processing such as frequency processing to output the processed image by displaying

20 it on a display such as a CRT or printing it on film by a printer. In such frequency processing, image processing is executed by decomposing the image of interest into image coefficients of a plurality of frequency bands and increasing or decreasing the image

25 coefficient values of every frequency band individually.

On the other hand, it is common practice to

uniformalize a histogram (frequency distribution) of

image densities (pixel values) by using a density

histogram uniformalizing method [e.g., see "Digital

Image Processing [1] for Understanding Images", pp.

5   133 - 135, by Junichiro Toriwaki, published by Shokodo,

First Edition, Fourth Printing). Using this method

makes it possible to utilize a given density range

efficiently so that image contrast is improved.

     The above method attempts to obtain a desired

10   frequency processing effect by changing the values of

frequency coefficients. However, this means nothing

more than altering the strength of coefficient values

and does not involve the idea of controlling a

histogram of coefficient values after a coefficient

15   conversion. More specifically, the conventional

method of increasing or decreasing coefficient values

involves only increasing or decreasing coefficient

values individually on a per-frequency-band basis and

does not take into consideration a coefficient

20   histogram of each frequency band. This makes it

necessary to adjust coefficients by trial and error in

order to obtain the desired effect. Further, when the

value of a frequency coefficient is merely changed,

this has an effect upon the dynamic range of the image

25   after it has been processed and there are instances

where artifacts such as overshoot occur at the edge

(contour) of the image.

Further, though image contrast can be improved by uniformalizing a pixel-value histogram, as indicated in the reference cited above, this method implements gray-level conversion processing and not frequency

5   processing, thereby making it impossible to adjust components on a per-frequency-band basis.

The present inventors have discovered that an image of desired contrast is obtained by controlling the frequency distribution of coefficient values of

10   every frequency band in accordance with the particular objective. In the examples of the prior art mentioned above, however, there is no implementation of a coefficient conversion that takes into account a frequency distribution of coefficient values obtained

15   after a coefficient conversion.

In view of the state of the prior art described above, there is need for an image processing apparatus and method whereby the contrast of an image of interest can be improved efficiently and effectively.

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SUMMARY OF THE INVENTION

According to one aspect of the present invention, there is provided, an image processing apparatus comprising:

25   decomposing means for decomposing an image into components of a plurality of frequency bands;

converting means for converting coefficient

values with regard to at least one frequency band of
the plurality of frequency bands in such a manner that
a frequency distribution of coefficient values of
every frequency band will become a prescribed

5   frequency distribution; and

generating means for generating an image using
the coefficient values obtained by the converting
means.

According to another aspect of the present

10   invention, there is provided, an image processing
method comprising:

a decomposing step of decomposing an image into
components of a plurality of frequency bands;

a converting step of converting coefficient

15   values with regard to at least one frequency band of
the plurality of frequency bands in such a manner that
a frequency distribution of coefficient values of
every frequency band will become a prescribed
frequency distribution; and

20   a generating step of generating an image using
the coefficient values obtained by the converting step.

Other features and advantages of the present
invention will be apparent from the following
description taken in conjunction with the accompanying

25   drawings, in which like reference characters designate
the same or similar parts throughout the figures
thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated

5   in and constitute a part of the specification,

illustrate an embodiment of the invention and,

together with the description, serve to explain the

principles of the invention.

Fig. 1 is a block diagram illustrating the

10   structure of an X-ray photography apparatus according

to an embodiment of the present invention;

Fig. 2 is a flowchart illustrating the procedure

of image processing in the X-ray photography apparatus

of this embodiment;

15   Fig. 3 is a diagram illustrating an example of a

coefficient conversion table that uses a histogram

uniformalizing method;

Fig. 4 is a diagram illustrating an ideal example

of coefficient values that have undergone a

20   coefficient conversion by a coefficient conversion

table that uses a histogram uniformalizing method;

Fig. 5 is a diagram illustrating a conversion

table based upon a combination of a coefficient

conversion table that uses a histogram uniformalizing

25   method and a coefficient conversion table of linear

form; and

Figs. 6A to 6C are diagrams illustrating a coefficient decomposition circuit and a restoration circuit that employ a discrete wavelet transform.

5   DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

A preferred embodiment of the present invention will now be described in detail in accordance with the accompanying drawings.

10   Disclosed in this embodiment is an image processing apparatus that executes frequency processing. Specifically, the apparatus converts coefficient values in such a manner that a frequency distribution of coefficient values of every frequency

15   band will take on a desired form.

Fig. 1 is a block diagram illustrating the structure of an X-ray photography apparatus 100 according to a preferred embodiment of the present invention. The X-ray photography apparatus 100 has a

20   function for executing effective image processing when an image that has been captured by photography is output on film or on a monitor. The X-ray photography apparatus 100 includes a data acquisition circuit 105, a preprocessing circuit 106, a CPU 108, a main memory

25   109, a control panel 110, an image display unit 111 and an image processing circuit 112. These are interconnected by a CPU bus 107 so as to be capable of

exchanging data with one another.

The data acquisition circuit 105 and preprocessing circuit 106 in the X-ray photography apparatus 100 are interconnected, and a two-

5 dimensional X-ray sensor 104 and X-ray generating circuit 101 are connected to the data acquisition circuit 105. Furthermore, the image processing circuit 112 is constructed to include a frequency-component decomposition circuit 113, a coefficient

10 conversion circuit 114, a restoration circuit 115 and a changing circuit 116. These circuits are connected to the CPU bus 107.

The functions of the above-mentioned components of the X-ray photography apparatus 100 will become

15 clear from the description that follows.

The main memory 109 in the X-ray photography apparatus 100 set forth above stores a control program and various data necessary for processing by the CPU 108 and also functions as the working memory of the

20 CPU 108. The CPU108 employs the main memory 109 to control the overall operation of the apparatus in accordance with an operation performed at the control panel 110. As a result, the X-ray photography apparatus 100 operates in the manner set forth below.

25 First, when the user enters a photography command via the control panel 110, the command is sent to the data acquisition circuit 105 by the CPU 108. Upon

receiving the photography command, the data

acquisition circuit 105 executes X-ray photography by

controlling the X-ray generating circuit 101 and two-

dimensional X-ray sensor 104.

5   In X-ray photography, the X-ray generating

circuit 101 emits an X-ray beam 102 toward a specimen

103. The X-ray beam 102 emitted from the X-ray

generating circuit 101 passes through the specimen 103

while being attenuated and arrives at the two-

10   dimensional X-ray sensor 104, which responds by

outputting an X-ray image signal. In this embodiment,

it is assumed that the specimen 103 is a human body.

That is, the X-ray image that is output from the two-

dimensional X-ray sensor 104 is an image of the human

15   body.

The data acquisition circuit 105 converts the X-

ray image signal, which is output from the two-

dimensional X-ray sensor 104, to a digital signal and

supplies the digital signal to the preprocessing

20   circuit 106 as X-ray image data. The preprocessing

circuit 106 subjects the signal (X-ray image data)

from the data acquisition circuit 105 to preprocessing

such as offset correction processing and gain

compensation processing. The X-ray image data that

25   has undergone preprocessing in the preprocessing

circuit 106 is transferred as original image data to

the main memory 109 and image processing circuit 112

via the CPU bus 107 under the control of the CPU 108.

The frequency-component decomposition circuit 113
in the image processing circuit 112 subjects the
original image to a discrete wavelet transform (DWT)
5   and obtains a coefficient (a wavelet transform
coefficient) of each frequency band. On the basis of
a frequency distribution of the coefficient values of
each of the frequency bands obtained by the frequency-
component decomposition circuit 113, the coefficient
10   conversion circuit 114 generates a coefficient
conversion table that is for the purpose of making
this frequency distribution a frequency distribution
of a prescribed shape, and uses this coefficient
conversion table to convert the frequency coefficients
15   that have been calculated by the frequency-component
decomposition circuit 113. Finally, the restoration
circuit 115 subjects the coefficients that have been
obtained by the coefficient conversion circuit 114 to
an inverse discrete wavelet transform (inverse DWT) to
20   obtain an image that has undergone frequency
processing. Further, the changing circuit 116 changes
the conversion characteristic (conversion table) of
the coefficient conversion circuit 114 based upon a
command, etc., from the control panel 110. The image
25   that has been obtained by the restoration circuit 115
is stored in an external storage device (not shown) or
is displayed on the image display unit 111.

The operation of the X-ray photography apparatus according to this embodiment having the structure set forth above will now be described in greater detail. Fig. 2 is a flowchart illustrating the procedure of

5   image processing in the X-ray photography apparatus 100 of this embodiment.

The original image obtained by the preprocessing circuit 106 is transferred to the image processing circuit 112 via the CPU bus 107 as described above.

10   First, at step S201, the frequency-component decomposition circuit 113 of the image processing circuit 112 subjects the original image, which is represented by $f(x,y)$, to a two-dimensional discrete wavelet transform, calculates coefficients on a per-

15   frequency-band basis and outputs the coefficients.

The discrete wavelet transform will be described with reference to Figs. 6A and 6B. Fig. 6A is a diagram illustrating the structure of the frequency-component decomposition circuit 113, and Fig. 6B is a

20   diagram illustrating an example of the structure of a two-level transform coefficient group obtained by the two-dimensional DWT processing.

The entered image signal is separated into an even-numbered address signal and an odd-numbered

25   address signal by a combination of a delay element and downsamplers, and the address signals are subjected to filter processing by two filters p and u. In Fig. 6A,

reference characters s and d represent low-pass and
high-pass coefficients, respectively, which prevail
when one level of decomposition is applied to each of
the one-dimensional image signals. It is assumed that

5   these coefficients are calculated as follows:

$$d_n = x_{2n+1} - floor[(x_{2n}+x_{2n+2})/2]$$

$$s_n = x_{2n} + floor[(d_{n-1}+d_n)/4]$$

where x_n represents the pixel value of an original
image that is to undergo conversion, and floor [ ]

10   represents a floor function known in the art.

By virtue of the above processing, a one-
dimensional discrete wavelet transform is applied to
the image data. A two-dimensional discrete wavelet
transform is achieved by executing the above-described

15   one-dimensional transform successively along the
horizontal and vertical directions of the image. As
the details of this processing are well known, they
need not be described here.

Fig. 6B shows an example of the structure of a

20   two-level transform coefficient group obtained by the
two-dimensional DWT processing. The image signal is
decomposed into coefficient groups HH1, HL1, LH1, ···,
LL of a plurality of different frequency bands. Here
HH1, HL1, LH1, ···, LL are also referred to as

25   subbands and each indicates a coefficient group of
every frequency band.

Next, among the subbands obtained at step S201,

the subbands of HL, LH, HL indicating high-frequency

coefficients are subjected to analysis at step S202

for flattening (uniformalizing) the histogram of

coefficient values. A coefficient conversion table is

5   created at step S203 based upon the result of analysis.

According to this embodiment, the six subbands HH1,

HL1, LH1, HH2, HL2 and LH2 are subjected to a

coefficient conversion. However, it will suffice to

apply conversion processing to the coefficients of all

10   or some of the subbands (frequency bands) in

accordance with the particular objective, as by

applying the coefficient conversion only to HH1, HL1

and LH1. For example, if it is desired to improve the

contrast of high-frequency components, the

15   coefficients of HH1, LH2 and LH1 are selected. If it

is desired to improve the contrast of the next lower

range of frequency bands, then the coefficients of HH2,

HL2 and LH2 are selected.

By way of example, in a case where a histogram of

20   coefficient values is uniformalized, it will suffice

to create a cumulative histogram of coefficient values

on a per-subband basis and normalize the shape of the

cumulative histogram to obtain a coefficient

conversion table (coefficient conversion function).

25   Specifically, it will suffice to create a cumulative

histogram (cumulative frequency distribution) by

plotting coefficient values along a horizontal axis

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and the cumulative frequency of the coefficient values
along a vertical axis, and obtain a coefficient
conversion table by substituting input coefficient
values for the horizontal axis of the cumulative

5 histogram and output coefficient values for the
vertical axis. An example of a coefficient conversion
table thus created is a coefficient conversion table
301 illustrated in Fig. 3. Specifically, Fig. 3 is a
diagram illustrating an example of a coefficient

10 conversion table for converting coefficient values, on
a per-frequency-band basis, calculated by the
frequency-component decomposition circuit 113. The
horizontal axis is a plot of input coefficients and
the vertical axis a plot of output coefficients. The

15 curve 301 in Fig. 3 corresponds to the coefficient
conversion table. The coefficient conversion table
301 is used in the coefficient conversion circuit 114.
It should be noted that actual coefficient values take
on a positive and negative values. Though the

20 conversion function (conversion table) is originally
an odd function, therefore, in Fig. 3 only the first
quadrant thereof is illustrated. Further, a
cumulative frequency distribution need not be used as
is. Rather, the distribution may be smoothened and

25 the coefficient conversion table may be created based
upon the smoothened distribution. In such case the
smoothing can be implemented as by a method of

approximating the cumulative frequency distribution
using a polynomial.

The scale along the vertical axis of the
conversion table of Fig. 3 can be enlarged or reduced
5   at step S204 to such an extent that coefficient values
after conversion will not exceed a maximum value. If
this is done, the absolute value of a coefficient
value can be adjusted while the flatness of the
histogram of coefficient values is maintained. For
10   example, if the scale along the vertical axis is
reduced, the values of coefficients after conversion
become larger and the frequency of appearance of each
coefficient declines. Conversely, if the scale along
the vertical axis is enlarged, the values of
15   coefficients after conversion become smaller and the
frequency of appearance of each coefficient increases.
This makes it possible to adjust the frequency
processing effect. Generally, a sharpening effect is
obtained if coefficients are increased in value and a
20   smoothing effect is obtained if coefficients are
reduced in value.

Next, at step S205, the coefficient conversion
circuit 114 uses the coefficient conversion table 301,
which has been generated as set forth above, to
25   convert the coefficients generated at step S201. When
a coefficient value of a subband is converted using
the coefficient conversion table 301, the histogram of

coefficient values after the conversion ideally takes
on the form shown at 401 in Fig. 4. Specifically, Fig.
4 is a diagram illustrating an example of a frequency
distribution of coefficient values after conversion in

5   a case where the coefficient conversion has been
performed using the coefficient conversion table 301.
In Fig. 4, the horizontal axis is a plot of
coefficient values and the vertical axis a plot of
frequency of appearance of the coefficient values. If

10 the scale along the vertical axis is altered, the
height (frequency) and width (range of coefficient
values) of the line 401 changes. It should be noted
that a change in the coefficient conversion
characteristic (conversion table), such as a change in

15 scale, can be performed by the changing circuit 116
based upon a command, etc., from the control panel 110.

Thus, coefficient conversion processing according
to this embodiment is such that a coefficient
conversion is carried out in such a manner that a

20 frequency distribution of coefficient values after
conversion will take on a prescribed shape (e.g., a
flat shape). In particular, it has been confirmed
that if the frequency distribution of coefficient
values is uniformalized as shown in Fig. 4 and

25 restoration processing (described later) is executed,
an image of enhanced contrast is obtained. In other
words, in accordance with such flattening of a

coefficient-value histogram, frequency processing of an image can be executed effectively and efficiently.

An improvement in contast according to the prior art and an improvement in contrast according to the

5   above embodiment will be described. An improvement in contrast by uniformalization of a density histogram according to the prior art improves the contrast of the overall image; it does not improve the contrast of a specific frequency band. By comparison, the above

10   embodiment is capable of improving the contrast of a specific frequency band. The contrast of a specific frequency band signifies the contrast of an image that has undergone reconstruction processing using only the coefficient of the specific frequency band.

15   The restoration circuit 115 executes processing for an inverse discrete wavelet transform at step S206 using all of the coefficients after they have been changed by the coefficient conversion circuit 114 in the steps S202 to S205.

20   Fig. 6C is a diagram illustrating the structure of the restoration circuit 115. Entered coefficients are processed by two filters u and p and the signals are superimposed after upsampling to generate an output image signal x'. The processing involved is

25   represented by the following equations:

$$x'_{2n} = s'_n - floor[(d'_{n-1}+d'_n)/4]$$
$$x'_{2n+1} = d'_n + floor[(x'_{2n}+x'_{2n+2})/2]$$

By virtue of the above processing, a one-dimensional inverse discrete wavelet transform is applied to coefficients. A two-dimensional inverse discrete wavelet transform is achieved by executing

5 the above-described one-dimensional inverse transform successively along the horizontal and vertical directions of the image. As the details of this processing are well known, they need not be described here.

10 In the foregoing, control is exercised so as to flatten the frequency distribution of converted coefficient values of each of the frequency bands, as illustrated in Fig. 4. However, this does not impose a limitation upon the shape of the frequency

15 distribution of converted coefficient values. For example, a shape in which the central portion of the distribution is peak-shaped, a linear shape that is ascending or descending, or a shape that is based upon an ideal coefficient-value frequency distribution of

20 an actual image can be adopted appropriately as the shape of the target frequency distribution. In a case where the frequency distribution is made an ascending straight line, this signifies that a normal frequency of appearance having a large amplitude in the

25 reconstructed image increases in proportion to the wave height. It should be noted that such a frequency-distribution shape can be decided

experimentally in accordance with the object of
processing or the particular objective.

Furthermore, in a modification of frequency-
distribution control, only a coordinate-value

5 histogram within a prescribed local range of
coefficient values can be flattened selectively using
a conversion table of the kind shown in Fig. 5.
Specifically, Fig. 5 is a diagram illustrating an
example of a coefficient conversion table in a manner

10 similar to that of Fig. 3. Reference numeral 501 in
Fig. 5 denotes a range of coefficient values in which
the histogram is to be flattened, and reference
numeral 502 represents the coefficient conversion
table. The portion corresponding to the range 501 of

15 coefficient values defines a shape in which the
histogram is flattened. The portion corresponding to
the range of other coefficient values defines a
straight line whose slope is 1, so that no conversion
of coefficients will take place. Generally, in a

20 high-frequency subband, the coefficient-value range
501 (a range of small coefficient values) indicates a
range corresponding to valid information, such as
microstructures in a continuous structure (an
anatomical structure in the human body), and the range

25 of larger coefficient values indicates a range
corresponding to an edge portion such as the contour
of a structure. In other words, the coefficient

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conversion for histogram uniformalization is made to act solely upon the coefficient-value range 501, and the coefficient values in other ranges are not changed. It will suffice if the coefficient-value range 501 is

5   set so as to take on a certain ratio with respect to the overall range of coefficient values (e.g., a ratio of 10% of the overall range).

In a case where the coefficient conversion table shown in Fig. 5 is used, contrast is enhanced in

10   excellent fashion in the image area of the reconstructed image that corresponds to the coefficient-value range 501, and coefficients are held unchanged at an edge portion, which is an image area that corresponds to the other range of coefficient

15   values. An effect obtained, therefore, is that the edge structure is preserved (i.e., false contouring does not occur). That is, effective and efficient frequency processing can be executed while suppressing artifacts such as so-called overshoot. Further, since

20   large coefficient values are held unchanged, a fluctuation in the dynamic range of the reconstructed image is suppressed. Furthermore, in a case where such a coefficient conversion table is used, the contrast enhancing effect of the image area

25   corresponding to the coefficient-value range 501 can be adjusted by altering the scale along the vertical axis, as mentioned above. A further advantage is that

the coefficient-value range 501 also is changed in accordance with the image of interest, the subband of interest and the objective of processing.

Thus, in accordance with this embodiment, as
5   described above, a coefficient conversion is performed in such a manner that a frequency distribution of coefficient values after conversion defines a prescribed shape, whereby a desired contrast enhancing effect can be obtained efficiently. For example, in a
10 case where a coefficient conversion is performed using a coefficient conversion table that is in accordance with the histogram flattening method and restoration processing is then executed, an excellent contrast enhancing effect can generally be obtained.

15 Furthermore, by using a coefficient conversion table so designed that a conversion characteristic based upon the histogram flattening method is adopted with regard to a range of coefficient values for which the absolute value is equal to or less than a
20 predetermined value while the coefficient values are kept unchanged with regard to a range of coefficient values for which the absolute value exceeds the predetermined value, valid portions that correspond to microstructures or the like can be enhanced in
25 contrast effectively and efficiently without producing artifacts such as false contours at edge portions in an image after processing. Furthermore, holding large

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coefficient values unchanged has the effect of

enabling suppression of fluctuation in the dynamic

range of the reconstructed image. The reason for this

is that there are many cases where a fluctuation in

5   dynamic range is produced by a change in large

coefficient values. In addition, by altering the

scale along the vertical axis of the coefficient

conversion table, coefficient values after conversion

are altered at a prescribed ratio uniformly and the

10   contrast enhancing effect can be adjusted.

Furthermore, the decomposition of an image into

frequency components is not limited to a discrete

wavelet transform. The decomposition can be achieved

using other methods, such as by a Laplacian pyramid

15   transform. Moreover, it is permissible to use a

method of calculating high- and low-frequency

components employing the so-called running-mean method.

In such case a high-frequency image is converted using

a histogram uniformalizing method [processing

20   equivalent to histogram equalization in image space;

see the above-mentioned reference ("Digital Image

Processing for Understanding Images")]. The high-

frequency components are created by the frequency-

component decomposition circuit 113, the high-

25   frequency components are converted using a conversion

table that has been created by the coefficient

conversion circuit 114 based upon the histogram

uniformalizing method, and the high-frequency

components that have been converted by the coefficient

conversion circuit 114 are added to the low-frequency

components by the restoration circuit 115, whereby a

5   processed image is obtained. Thus, though the present

embodiment has been described using a discrete wavelet

transform, the technical idea of the embodiment is

applicable also to a case where use is made of other

processing for decomposing an image into frequency

10   components.

It goes without saying that the object of the

invention is attained also by supplying a storage

medium storing the program codes of the software for

performing the functions of the foregoing embodiment

15   to a system or an apparatus, reading the program codes

with a computer (e.g., a CPU or MPU) of the system or

apparatus from the storage medium, and then executing

the program codes.

In this case, the program codes read from the

20   storage medium implement the novel functions of the

embodiment and the storage medium storing the program

codes constitutes the invention.

Examples of storage media that can be used for

supplying the program code are a floppy disk, hard

25   disk, optical disk, magneto-optical disk, CD-ROM, CD-R,

magnetic tape, non-volatile type memory card or ROM,

etc.

Further, besides the case where the aforesaid functions according to the embodiment are implemented by executing the program codes read by a computer, it goes without saying that the present invention covers

5   a case where an operating system or the like running on the computer performs a part of or the entire process in accordance with the designation of program codes and implements the functions according to the embodiment.

10   It goes without saying that the present invention further covers a case where, after the program codes read from the storage medium are written in a function expansion board inserted into the computer or in a memory provided in a function expansion unit connected

15   to the computer, a CPU or the like contained in the function expansion board or function expansion unit performs a part of or the entire process in accordance with the designation of program codes and implements the functions of the above embodiment.

20   As many apparently widely different embodiments of the present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the

25   appended claims.